AP Biology

Unit 4 – Biological Interactions

Notes

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Section 1 – Molecular & Cellular Interactions

1.1 – What determines how molecules interact?

Molecules are made of atoms with unique properties giving them unique chemical structures & behaviors. Lipids for example are hydrophobic and will repel hydrophilic substances, which partly gives a membrane its selective permeability. The **proteins** embedded in the membrane transport substances only based on their ability to interact with them. **DNA** and **RNA** are able to bond during transcription due to their similar structure, directionality and affinity to form hydrogen bonds. A ligand only binds to specific receptors that conform to their shape & have atoms allowing them to bond temporarily.

1.2 – How does a molecule's shape influence its interactions?

Hopefully by now you have seen how structures of substances are quite suited to their functions in living things. The chemical composition of molecules determines its shape by forming bonds at certain locations that hold together its specific structure. **Carbohydrates** with their ring structures are ideal for forming long chains of energy storage molecules that can easily be cleaved when needed for energy. They also serve as the structural components of plant bodies, such as **cellulose**. **Lipids** have long chains but of mostly carbon & hydrogen in a long, linear structure making it harder for them to be hydrolyzed & thus releasing more energy than carbohydrates. Lipids are also well suited to form thick stacked layers that can act as **insulation** for organisms.

1.3 – How is a cell's shape suited to its function?

Cells all have specific tasks and their DNA expressed differentially based on its unique set of transcription factors provides this architectural blueprint. Cells must be able to exchange materials and the various mechanisms of cell transport have already been discussed in unit 2 but now we will discuss how cell shapes influence their transport. The membrane is the only point at which materials can be *exchanged* and thus acts as a **gateway**. Many cells are specialized for bringing materials into cells such as root cells of plants. Roots are extremely branched which allows for an increase in available points of entry. Similarly, the cells of roots are highly folded allowing more membrane **surface area** to be in contact with the soil. The same trend is seen for example in intestinal cells that specialize in absorbing nutrients to transfer to capillaries. The intestinal cells are highly folded, again increasing membrane surface area.

By increasing membrane surface area a cell can assure that materials are most efficiently transported in and out of the cell. The general trend we see and the rule you should remember is that as a cell increases in size, the volume within increases much faster than the membrane surface area. To counter this effect, cells specializing in transport have highly folded membranes that increase surface area to volume ratios. This is also the main reason why cells must remain small instead of growing too large where their rate of material movement would be hindered by too few points of transport compared to the inside volume.

1.4 – How do organelles determine a eukaryote cell's function?

The organelles of eukaryotes are also suited to their specific functions and interactions. Cells containing many **mitochondria** or **chloroplasts** are suited as energy conversion cells like liver cells of animals & leaves of plants. Protein producing cells usually contain large amounts of **Rough ER** & **Golgi;** lipids are made by the **Smooth ER,** while cells specializing in detoxification have large amounts of **lysosomes** & **peroxisomes**. Some cells even lose organelles to be more efficient like red blood cells that eject the large nucleus so they may bind & transport large amounts of materials quickly.

Section 2 – Enzyme Structure & Function

2.1 – How is energy a factor in molecular interactions?

Even when molecules are able to react with other molecules or undergo a change in their own shape, there is usually some energy barrier they must overcome to do so. Sometimes ions can donate electrons which provide chemicals with energy, like in the electron transport chain. These transfers need to be conducted at specific times and in specific locations so as not to waste energy. Other times a molecule such as glucose needs to be rearranged in a specific way to make it optimal for ATP production. Glucose and other molecules will not spontaneously change into desired forms quickly or accurately without some assistance. This role of providing an optimal location & condition for molecular change is provided by enzymes. **Enzymes** are proteins acting as catalysts: speeding up reactions without being consumed by the reaction (they are reusable).

2.2 – How is an enzyme's structure suited to its function?

Enzymes are proteins made of amino acids in a set **primary structure** determined by a gene. The primary structure contains various amino acids with different chemical properties which allow hydrogen bonds between them to form **secondary structure** coils, twists and folds. A final **tertiary structure** is achieved when various ionic & covalent bonds link different coils, folds & twists together. This final shape is a 3D form with a specific location called the **active site** where catalysis happens. The active site contains amino acid groups which are specific to certain reacting molecules called **substrates**. Other molecules called **cofactors** & **coenzymes** also reside in the active site, which provide more favorable conditions for substrates to react in. It is this unique 3D shape & set of chemicals making up an enzyme that allows them to have specificity for certain substrates.

2.3 – What does an enzyme do that makes a reaction happen?

The amount of energy required for substrates to change into products is called the **energy of activation/activation energy** (**Ea**). Glucose contains 686kcal of chemical energy within the bonds holding it together. Although it would dissociate in water eventually, the energy released would neither happen in a proper location nor release its maximum energy content. When catalyzed by numerous enzymes, glucose releases energy in steps, with each step being coupled to another reaction that can absorb the released energy. Each enzyme's active site assures the molecule is broken apart in just the right place based on where glucose binds to.

By providing a unique microenvironment to assure molecules are broken down or put together, the Ea for an enzyme catalyzed reaction is much lower than for an uncatalyzed reaction. Enzymes shift in shape to cause strain on substrate bonds which helps them break or moves substrates closer together to attach them. This conformation change of enzymes around substrates is called **induced-fit**. The amount of energy of the substrate or the products is never changed, only the energy needed is lower due to the decrease in time taken and total energy required. Draw figure 8.13 on p.153 comparing an enzyme & non-enzyme reaction.

2.4 – Why are enzymes such a big deal????

Enzymes direct the formation, timing, regulation and…everything else…of all carbohydrates, lipids, DNA/RNA (nucleic acids) and proteins. Aren't all of those molecules essential to cells, tissues, organs and… umm all parts of life??? YES. What about the ncRNA that regulates RNA? Well, to transcribe & translate the ncRNA, you need ENZYMES. Glad we're all clear now as to why enzymes are such a big deal.

Section 3 – Enzymes & Their Interactions

3.1 – What environmental factors influence enzyme reactions?

Because enzymes have specific 3D shapes dependent on their molecule interactions, any change in the environment that can alter these molecule interactions can alter the enzyme and thus its functionality. Temperature shifts cause molecules to change speed and enzymes evolved in high temperature environments will not work well in cold environments for example. pH shifts the amount of H+ ions which are very reactive. Enzymes accustomed to acidic conditions rely on the acidic protons for their reactions so changing to a neutral pH decreases these H+ ions and thus the reaction efficiency. Any condition that causes the protein to lose its tertiary structure **denatures** the enzyme, leading to severe loss of function. Figure 8.16 shows some temperature & pH examples for different enzymes.

3.2 – What is the typical rate trend of an enzyme?

Enzyme rates follow a very predictable pattern. As substrates are increased in concentration, they will bind to enzymes at an increasing rate since more substrate increases the probability they will collide and react with an enzyme. At some point however, the enzymes become saturated and remaining substrates will have a wait-time to get access to the next available enzyme. In general we measure the rate of an enzyme at the half-way point to its saturation point [**maximum velocity** (**V_{max}**)], also known as **1/2 V_{max}**. This rate is when the reaction is at its maximum efficiency.

3.3 – How does competition affect enzyme velocity & efficiency?

Competitive inhibitors directly compete with a substrate for an enzyme's active site. This competition does not keep the enzyme from reaching its V_{max} but it does take longer since the active sites will be filled with inhibitors at some times, increasing substrate wait time & decreasing enzyme efficiency (time spent doing PRODUCTIVE work). **Noncompetitive inhibitors** bind to a location away from the active site called an **allosteric site**, causing affected enzymes to change their shape, which alters the shape of the active site. These inhibitors don't decrease overall enzyme efficiency but decrease enzyme functionality. Fewer functional enzymes mean that the V_{max} is always lower with noncompetitive inhibitors but unaffected enzymes still have normal efficiency.

3.4 – How do allosteric sites function in enzyme regulation?

Enzymes just like all proteins need to be regulated. Allosteric sites are a critical part of an enzyme's regulation since they act as on and off switches. In many instances, the molecules involved in an enzyme reaction are also its regulatory molecules.

For example, when glucose levels are high in the blood, enough is present to bind to pancreas cell membrane enzymes. These enzymes are then allosterically activated, signaling a pathway that releases insulin and ultimately removes glucose from the blood. When blood glucose levels drop from being absorbed into tissues, the glucose detaches from the pancreas cell enzyme and it is shut down.

Another example is certain enzymes required to degrade cyclins in cell division. If these enzymes are inhibited, they cannot degrade cyclins and cell division will continue uncontrollably. This could occur if a faulty gene is expressed continuously, leading to a constant supply of allosteric inhibitor molecules.

Section 4 – Physiological Interactions

4.1 – What interactions are important in prokaryote physiology?

Prokaryotes rely on their single cell to respond to stimuli & carry out normal life functions. When nutrients are scarce, prokaryotes can sense these low levels and use feedback pathways to activate or inhibit gene expression. For example, when certain amino acids become available, the amino acids act as corepressors that inhibit the normally active operon transcribing genes to make those amino acids. Prokaryotes can also sense closely related members of their population from similar chemicals they secrete. In response to similar members they will not release any toxins but when less-related individuals are nearby, toxins can be secreted that inhibit their growth.

4.2 – What interactions are important in plant physiology?

Plants need CO_2, water & light to survive. A constant battle is their need for light at a cost of water loss. This loss of water due to evaporation from leaves is called **transpiration**. As factors such as wind & heat move water molecules away from leaves surfaces, this creates areas of low water potential compared to the water-filled stems & leaves with high water potential. Adhesion & cohesion keep water in a continuous stream and the water potential difference keeps it flowing upwards. Too much water loss leads to the vacuoles of plant cells **plasmolyzing**, and can kill the plant. To counter the effects of excessive transpiration, plants can close their **guard cells**, preventing water from evaporating out of the **stomata** pores. The specially adapted C4 & CAM plants also have their unique solutions.

4.3 – What interactions are important in animal physiology?

The complex interactions of animals involve the nervous system, respiratory system, circulatory system and many others. We have seen numerous examples of how animals maintain homeostasis but the example below will detail how interactions between multiple systems involve gene regulation, cell communication & metabolism.

Suppose an aquatic mammal such as a seal routinely dives to low depths to reach a prime fish species as a food source. Some forces the seal must contend with include depleting oxygen levels, colder temperatures, decreased visibility and avoiding predators of its own. As oxygen levels become low, fermentation must take over. Low levels of oxygen lead to genes, usually inhibited by oxygen-dependent enzymes, becoming expressed. Increased levels of lactic acid bind to membrane receptors initiating a transduction pathway in fat cells. Energy cannot be generated by either pathway any longer to produce heat, so the transduction pathway actually leads to the conversion of saturated fats into unsaturated fats which releases heat into surrounding tissues. A decrease in light stimulates receptors in their eyes to convert from one form to another, thus increasing vision in low-light levels. Predator avoidance is based on sensory neurons picking up visual & chemical stimuli. If a predator is perceived in some way, nerves will send action potentials communicating the threat to the brain for integration and a proper decision will be made.

This is just one example of how many systems function together on a wide variety of levels. In the next few sections we will discuss interactions on a more ecological level but keep in mind that all processes in and between organisms and their environment involve multiple levels of interactions.

Section 5 –Community Interactions

5.1 – What factors limit population size?

Populations face interactions that limit their growth such as disease, **competition**, **predation**, **parasitism** & **herbivory**. These are considered **density-dependent factors** because the larger the population becomes, the more impact the factor has on the population. Other factors like weather & geologic events can affect population size no matter what the size and are called **density-independent factors**.

5.2 – How do population growth trends affect population size?

Some organisms exhibit **r-selection patterns** showing **exponential population growth**, small body size and quick life cycles with little to no parental care of offspring. Examples include bacteria, most invertebrates & many protozoa. Their growth curve has a "J-shape" as the population increases exponentially, seemingly without limits. However, without enough nutrients or building up of wastes, the populations usually crash after a certain point. The equation used to model exponential growth is: **$dN/dt = r_{max} N$** where the left side of the equation is the rate of change over some time interval. On the right side of the equation "**N**" is the size of the population and "**r_{max}**" is called the per-capita growth rate. Rmax is determined by the difference between the **birth rate (b)** & the **death rate (d)**.

Other organisms exhibit **k-selection patterns** showing **logistic population growth**, larger body size and longer life cycles with more parental care of offspring. Examples include most vertebrates & plants. Their growth curve has a "S-shape" as the population increases exponentially at first but then levels out at a point known as **carrying capacity**. The equation used to model exponential growth is: $dN/dt = r_{max} N ([K-N]/K)$. On the right side of the equation a new variable "**K**" is introduced and represents **carrying capacity**, a quantity representing the maximum population size the environment can support. This includes resources like food, sunlight, space, etc. All populations have a carrying capacity but small organisms usually don't reach it until their populations are massive since vast organisms only take up a small area and resources.

5.3 – How do community interactions affect population size?

Negative interactions cause populations to decrease. Predators serve as a limit to prey populations as do herbivores to plants. Parasites also play a role as they have a similar effect as predators would, by killing the organism. These interactions follow a cyclic pattern where the prey increases, followed by an increase in the consuming population. As the prey begins to decline, the consuming population will also decline. Competition also serves to limit populations by decreasing available nutrients and space for others. If these negative factors are removed, the population would grow exponentially, outside of any density-independent factors.

Positive interactions can help populations increase. **Mutualism** is a well-studied community interaction in which two species benefit from interacting. Some mutualisms are obligate while others are situational. Anemones & clownfish, insects & flowering plants and ants & fungi each provide a service to the other and benefit from interacting with each other. Some obligate mutualisms can cause the populations to decline however; if one of the populations declines or is removed from the relationship, the other will not receive its service from the other and may die out.

Section 6 – Ecosystem interactions

6.1 – How is an ecosystem structured?

An ecosystem is defined by the set of all organisms and their **biotic** & **abiotic** interactions. The individual **niche** of an organism includes its energy sources, how it serves as energy for others, and any other roles it plays or impacts it has in the ecosystem. Most ecosystems change in a predictable way over time until reaching a stable ecosystem, which is called **succession**. **Primary succession** structures an ecosystem starting from a landscape without life because no soil exists. Events like lava flows, glacier movement and formation of new islands from volcanic uprising can generate these barren areas. **Pioneer species** like bacteria begin to transform rock into soil slowly and then small mosses and lichens can begin to grow. From there larger plants like grasses and small trees germinate which draws in animals. In wet regions a forest may develop, where trees will out-compete smaller plants for light, or the region may remain dominated by grasses in drier regions. **Secondary succession** is when an event clears the life from a region but the soil remains and life can return more quickly with not having to generate soil. This occurs after fires, floods and human activities like logging and abandoned developed lands. Although the organisms may never be exactly the same, a similar ecosystem will always return.

6.2 – How is the health of an ecosystem determined?

Just like a healthy population relies on genetic variation, healthy ecosystems depend on **species richness**, measuring the diversity of species & their abundance. Even if the ecosystem has a large producer trophic level, it must be able to support the primary consumer level. For example if there is only 1 *type* of tree, not all primary consumers may be able to eat them and the ecosystem will crash. A healthy ecosystem has a producer level which accommodates all the primary consumers and the primary consumer level must accommodate the secondary consumers and so forth. Just measuring one **food chain** is not as useful as studying the **food web** of an ecosystem which shows all of the energy transfer interactions in an ecosystem.

6.3 – How does primary productivity predict ecosystem health?

Primary productivity is a measure of how much available energy exists in the total producer trophic level that can be transferred to the primary consumer level. Generally the flow of energy follows **the 10% rule** stating that only 10% of the energy in one trophic level is transferred and represented in the next trophic level. The total solar energy absorbed by producers does not directly equate to their energy; rather, about 10% of the solar energy is transformed into an increase in body mass. The 90% that seemingly disappears is used by the producers during cell respiration to fuel their needs of body maintenance & biochemical conversions. Much of this energy is also lost as heat during these reactions. If the primary productivity is less than the primary consumer level needs, the ecosystem will decline due to a lack of available nutrients for primary consumers.

6.4 – How does secondary productivity predict ecosystem health?

Secondary productivity is a measure of how much available energy exists in the primary consumer trophic level that can be transferred to the secondary consumer level, and follows the 10% rule again. We again see that 10% of the food consumed is able to add to a trophic levels body mass increase. The energy losses are also due to heat loss during cell respiration & other transformation reactions, but animals are not able to process and transform all the material they consume and much is passed as undigested food in feces. If the secondary productivity is less than the secondary consumer level needs, the ecosystem will decline due to a lack of available nutrients for secondary consumers.

Section 7 –Ecosystem disturbances

7.1 – What species impact ecosystems the most?

While all organisms have important niches, organisms known as **keystone species** impact an ecosystem in a major way. Proper recycling of nutrients is essential and **decomposers** carry out this essential role. Certain bacteria & most fungi take on this role by recycling dead organisms and transforming their matter into forms available for producers to take in from the soil. Disturbances that impact decomposers can devastate a community since the producers lose nutrients and with their decline in productivity, comes a decline in consumer populations. Some organisms provide the major habitats for other organisms such as trees in forests and corals in reefs. Disruptions to these keystone species usually lead to severe declines in the populations of many other species.

7.2 – How do toxins & pollutants impact ecosystems?

Toxins & pollutants usually have characteristics of enzyme inhibitors or protein degradation like most pesticides & human medications. As these chemicals enter the environment from runoff into aquatic habitats or leeching into soils, they are taken up by organisms. As they are consumed, the toxins usually remain accumulated in body tissue instead of being eliminated. As more and more are consumed, the toxins become magnified in the ecosystem and all can be impacted, even humans as we consume the organisms.

7.3 – How does land development impact ecosystems?

As human populations increase, the desire for land to be developed into areas usable by humans for various purposes increases. These developments can separate species, introduce chemicals and disrupt important interactions among organisms in their ecosystem. We must consider these effects as they may ultimately lead to decreased water & food supplies for us and all organisms.